Case Studies in Thermal Engineering 6 (2015) 226–237

Contents lists available at ScienceDirect

Case Studies in Thermal Engineering

journal homepage: www.elsevier.com/locate/csite

Thermal and optical efficiency investigation of a parabolic trough collector

C. Tzivanidis, E. Bellos *, D. Korres, K.A. Antonopoulos, G. Mitsopoulos

National Technical University of Athens, School of Mechanical Engineering, Thermal Department, Heroon Polytehniou 9, Zografou, 157 73 Athens, Greece

ARTICLE INFO

Article history:
Received 7 October 2015
Received in revised form
18 October 2015
Accepted 18 October 2015
Available online 10 November 2015

Keywords:
Parabolic trough collector
Heat convection coefficient
Thermal efficiency
Solidworks
Local concentration ratio
Optical efficiency

ABSTRACT

Solar energy utilization is a promising Renewable Energy source for covering a variety of energy needs of our society. This study presents the most well-known solar concentrating system, the parabolic trough collector, which is operating efficiently in high temperatures. The simulation tool of this analysis is the commercial software Solidworks which simulates complicated problems with an easy way using the finite elements method. A small parabolic trough collector model is designed and simulated for different operating conditions. The goal of this study is to predict the efficiency of this model and to analyze the heat transfer phenomena that take place. The efficiency curve is compared to a one dimensional numerical model in order to make a simple validation. Moreover, the temperature distribution in the absorber and inside the tube is presented while the heat flux distribution in the outer surface of the absorber is given. The heat convection coefficient inside the tube is calculated and compared with the theoretical one according to the literature. Also the angle efficiency modifier is calculated in order to predict the thermal and optical efficiency for different operating conditions. The final results show that the PTC model performs efficiently and all the calculations are validated.

1. Introduction

Fossil fuel depletion and global warming problem lead our society to the use of clean and abundant energy sources. Renewable energy sources are sustainable by producing zero greenhouse gas emissions and will be always available, so they seem to be the most suitable energy sources for the future. Solar energy is the oldest energy source ever used and is widely used by giving solutions in many applications, from industrial hot water supply to electricity production [1–4], especially in countries with a high solar irradiation level as Greece [5,6]. More specifically, concentrated solar collectors are able to produce high temperatures (over 400 °C) with high thermal efficiency. This is the fact that makes them a feasible and promising technology for solar desalination, solar chemistry applications, solar cooling (absorption and adsorption), solar hydrogen production and of course for Concentrated Solar Plants (CSP) [7].

The main solar technologies for electricity production are Linear Fresnel collectors, parabolic dish combined with a Stirling engine, parabolic trough collectors and solar tower (central receiver system) [8,9]. Parabolic trough collectors (PTC) cover the 90% of the total CSP systems [10] because this technology is the most mature among the concentrating collectors; it leads to light structure systems and is applied since decades [11]. Nowadays, many commercial CSP systems are operating

* Corresponding author.
E-mail address: bellose@central.ntua.gr (E. Bellos).

http://dx.doi.org/10.1016/j.csite.2015.10.005
2214-157X/

Nomenclature

A	area, m^2
C_L	local concentration ratio
c_p	specific heat capacity, kJ/kg K
D	diameter, m
F_R	heat removal factor
F'	collector efficiency factor
F''	flow efficiency factor
G_b	solar beam radiation, W/m^2
h	convection coefficient, W/m^2K
k	thermal conductivity, W/m K
K	Angle efficiency modifier
L	tube length, m
m	mass flow rate, kg/s
Nu	mean Nusselt number
Pr	Prandtl number
Q	Heat flux, W
Re	Reynolds number
T	Temperature, K
U_L	Losses coefficient, W/m^2K
W	Width, m

Greek symbols

β	peripheral absorber angle, °
ε	emittance
η	efficiency
θ	angular displacement in longitudinal direction, °
μ	dynamic viscosity, Pa s
ρ	reflectance
σ	Stefan–Boltzmann constant [$=5.67\cdot10^{-8}$ W/m^2K^4]
$(\tau\alpha)$	transmittance–absorptance product

Subscripts and superscripts

a	aperture
abs	absorbed
am	ambient
c	cover
ca	Cover-ambient
ci	inner cover
co	outer cover
fm	Mean fluid
in	inlet
loss	losses
m	mean
opt	optical
out	outlet
r	receiver
ri	inner receiver
ro	outer receiver
s	Solar
u	useful

in countries with high solar energy potential, as U.S.A. [12], Algeria [13,14] and Spain [15]. The basic parts of a PTC are an evacuated tube and a linear parabolic reflector. The reflector is made by bending a reflecting material into a parabolic shape and the evacuated tube is located in the focus line of this parabola. The main idea of this technology is the reflection of the solar beam radiation from the parabolic reflector towards to the evacuated tube in order to heat the working fluid. The general efficiency improvements and the cost reduction of PTC systems are essential factors for the further development of CSP systems worldwide [9,16]. Thus, many researches have been working in this field trying new ideas and optimizing the existing collectors [17,18].

According to the literature, a great amount of parameters that influence the PTC′s efficiency have been studied with numerical models and simulations tools. Wind influence on thermal efficiency is examined by Hachicha et al. [19] while extended optical analysis of concentrating collector is studied by many researchers, with Cheng et al. to use the Monte Carlo ray-tracing optical model in order to simulate a PTC [20] and Binotti et al. [10] to use FirstOPTIC method to calculate the optical analysis of the examined models. Ouagued et al. [16] solved a system of energy balance differential equations with Euler method and made an analysis for the influence of HTF price on the thermal energy cost. The use of synthetic oil nanofluid as the working fluid is studied by Sokhansefat et al. [21] and de Risi et al. [18] with the final results to conclude that the use of nanoparticles increases the heat transfer coefficient between the absorber and the working fluid.

In thermal performance studies, the majority of numerical studies use one dimensional heat transfer analysis [22–25] which is the simplest numerical method. Marif et al. [26] by using this method concluded that liquid water performs better than synthetic oil (TherminolVP-1™). Gong et al. [25] made both one and three dimension heat transfer analysis and proved that the two methods agree with the test results. Also, three dimensional studies are available in the literature [27–30]. Xu et al. [31] developed a dynamic model in order to study the performance of a PTC in transient operations and tested it with experimental data. Many other simulations have been developed with Engineering Equations Solver (EES) and have been validated with existing results [32–34]. On the other hand, simulations with well-known software exist in literature. Tsai and Lin [35] used Solidworks to simulate different kinds of reflectors for a PTC collector in order to maximize the thermal efficiency. Akbarimoosavi and Yaghoubi [36] used ANSYS and concluded that the high thermal conductive absorber materials lead the reduction of maximum peripheral temperature difference and so the thermal efficiency increases. Moreover, FLUENT is a very useful tool for simulations and many works have been met in bibliography [37–39]. The simulation by Mwesigye et al. [40] has a great interest because proves that the use of perforated plate inserts inside the tube increases the thermal efficiency by 1.2% with significant reduction in the absorber temperature. Also, many experimental works with numerical validation are available in the literature [41–46].